# COLORED STONES

# ASSIGNMENT 11

## COLOR, CHEMICAL PROPERTIES AND INCLUSIONS

### IDENTIFICATION, PRODUCTION, MARKETING, BUYING

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## I. A SYSTEM OF COLOR DESCRIPTION FOR GEMS.

The importance of an understanding, an appreciation, and a keen perception of color to a gemologist should be obvious. From this point forward in the study of colored stones, it is necessary to describe colors encountered in the various trade grades and varieties of the major species. Terms such as "apple green," "leaf green," "cerise," "mauve" and "scarlet" mean one thing to one person and something else to another. Thus, some standardized color-nomencalture system is essential to learn the color differences that determine desirability and relative value.

Experience has proved that there are important devidends to the jeweler who makes a study of color. In the western world, women tend to be much more conscious of color than men, with the result that they usually develop a much keener color perception. A study of color makes the student more aware of the colors around him, and a heightened perception of color is the usual result. This growing awareness of color nuances develops an ability to recommend color combinations to customers and to instill in them a deeper appreciation of the beauty of colored stones; this, in turn, means added sales effectiveness.

The study of color in all of its many aspects is not within the scope of this course, but the essentials to a basic understanding of a system of color terminology are outlined on the next several pages.

### A. What is Color?

Briefly, color is a sensation resulting from a stimulation of the eye by certain wavelengths of visible light. To better understand this phenomenon, the eye can be visualized as consisting of three types of receptors, each sensitive to approximately one-third of the visible spectrum, and a fourth type that registers brightness. If the three color receptors are stimulated equally, a balanced sensation is created that the brain interprets as white or colorless. If they are stimulated unequally, the perception of color results. For example, when the eye is exposed to a beam of light consisting predominantly of the longer (red) wavelengths of the visible spectrum, the sensation is red; if the radiation contains equal intensities of both red and yellow, a color that is intermediate between the two (orange) is perceived.

An object by itself has no color; instead, its color, as perceived by the eye, is the result of the particular wavelengths of light that the object is capable of reflecting or transmitting. Those wavelengths not transmitted by the object are absorbed by it. This partial absorption of certain wavelengths of light by an object that produces its color is referred to as SELECTIVE ABSORPTION, and it accounts for the color of all objects other than luminous bodies.

To observe the typical color of an object, it is necessary to illuminate it with a light source that contains approximately equal amounts of all the wavelengths of visible light. Daylight or its equivalent is used as the standard for color observation. Special artificial light sources that emit only a limited range of wavelengths (e.g., the sodium-vapor lamps used in some cities for street illumination) produce only a portion of the wavelengths found in sunlight; therefore, objects that normally appear as red or green in daylight, for example, do not appear in their true color under these special lamps.

One of the keys to an understanding of the color of different objects lies in the fact that most substances transmit and reflect almost all of the visible wavelengths of light but some more readily than others. The predominant wavelengths stimulate the corresponding receptors in the eye to a greater extent, and thus we perceive the object as being of that color.

## B. Color and Hue.

From the above discussion it can be seen that all sensation of vision is one of color, and it is by this means that an object is distinguished from its surroundings. In this broad sense, white, gray and black are colors, since they contrast with their surroundings. Also, dark red (maroon), light red (pink), orange and reddish orange are different colors, because each is a different sensation.

Hue in its narrowest sense refers to all color sensations other than white, gray or black. In order to eliminate any ambiguity in the use of the word color, we will refer to all color sensations other than white, gray or black as HUES or as vaiations of hues. Thus a gem can be described as being white, black or gray or of various hues (blue, yellow, blue-green, etc.). Hues are sometimes called CHROMATIC colors to distinguish them from the so-called ACHROMATIC colors of white, gray and black.

The term COLORLESS is applied to transparent (or, for all practical purposes, nearly transparent) substances that transmit equally well a balanced spectum of visible light; for example, a diamond without body color and a pane of glass.

In the sun's spectrum, which can be observed by passing a beam of sunlight through a glass prism to separate the various wavelengths, the average person is capable of distinguishing approximately 128 different hues, ranging from violet through red. Various combinations of red and violet that are not found in the sun's spectrum but that are observed elsewhere in nature and in man-made products account for approximately 22 additional hues. In other words, the average person is capable of observing and distinguishing about 150 pure hues.

These 150 pure hues are not to be confused with the total number of colors we can observe, since any given pure hue can vary from light to dark and from dull to intense. The total number of variations, or COLORS, that are detectable by the average person is estimated at approximately 1,000,000. Fortunately, for practical purposes, we do not have to be concerned with such fine distinctions as would be involved in sepating one million colors. Instead, we are only concerned with general classifications, each of which encompasses a large number of these colors.

To simplify the nomenclature, a given chromatic color is referred to by the pure hue it represents, in addition to descriptive prefixes that designate any deviation from the pure hue. The total description involves what are referred to as the three attributes of a color: HUE, TONE and INTENSITY.

As explained previously, hue is that attribute of a color that causes the eye to perceive it as differing from white, black or gray. It is this attribute that makes it possible to arrange colors in orderly sequence around the circumference of a COLOR WHEEL or COLOR CHART (see accompanying diagram). The simplest system of naming the intermediate hues is to use a method that gives a visual impression of them, avoiding the use of such indefinite terms as "apple green," "Venetian red" and "sky blue." For example, the hues from yellow to green on the color wheel are described as yellow, greenish-yellow, yellow-green, yellowish green and green. By this method, 24 hues can be dscribed and their relation to one another visualized easily. These distinctions are particularly important for grading emeralds, rubies and other colored stones.

Tone is that attribute of a color that causes the eye to perceive it as holding a position on a light-to-dark scale. To produce colors of different tones in paint, for example, different amounts of white or black pigment are added and it becomes lighter or darker. It should be noted that since white and black can be added to gray, it can also vary in tone. This is not true of white or black, however, since any variation from either one results in a tone of gray (one could not visualize black as being a "light" or "dark" black). Tone is particularly important in diamond grading, since the principal trade grades are based on tonal variations of yellow.

Having represented intervals of hues around a wheel, it is perhaps best to indicate intervals of tone by their postion on the "spokes" of the wheel, as shown on the accompanying diagram. For the purpose of describing the tonal variations of gemstones, the terms VERY DARK, DARK, MEDIUM, LIGHT and VERY LIGHT are sufficient. This is an arbitrary division of the scale, of course, since there is a gradual darkening of any hue from white to black. A vast number of tones are possible, each producing a different color sensation.

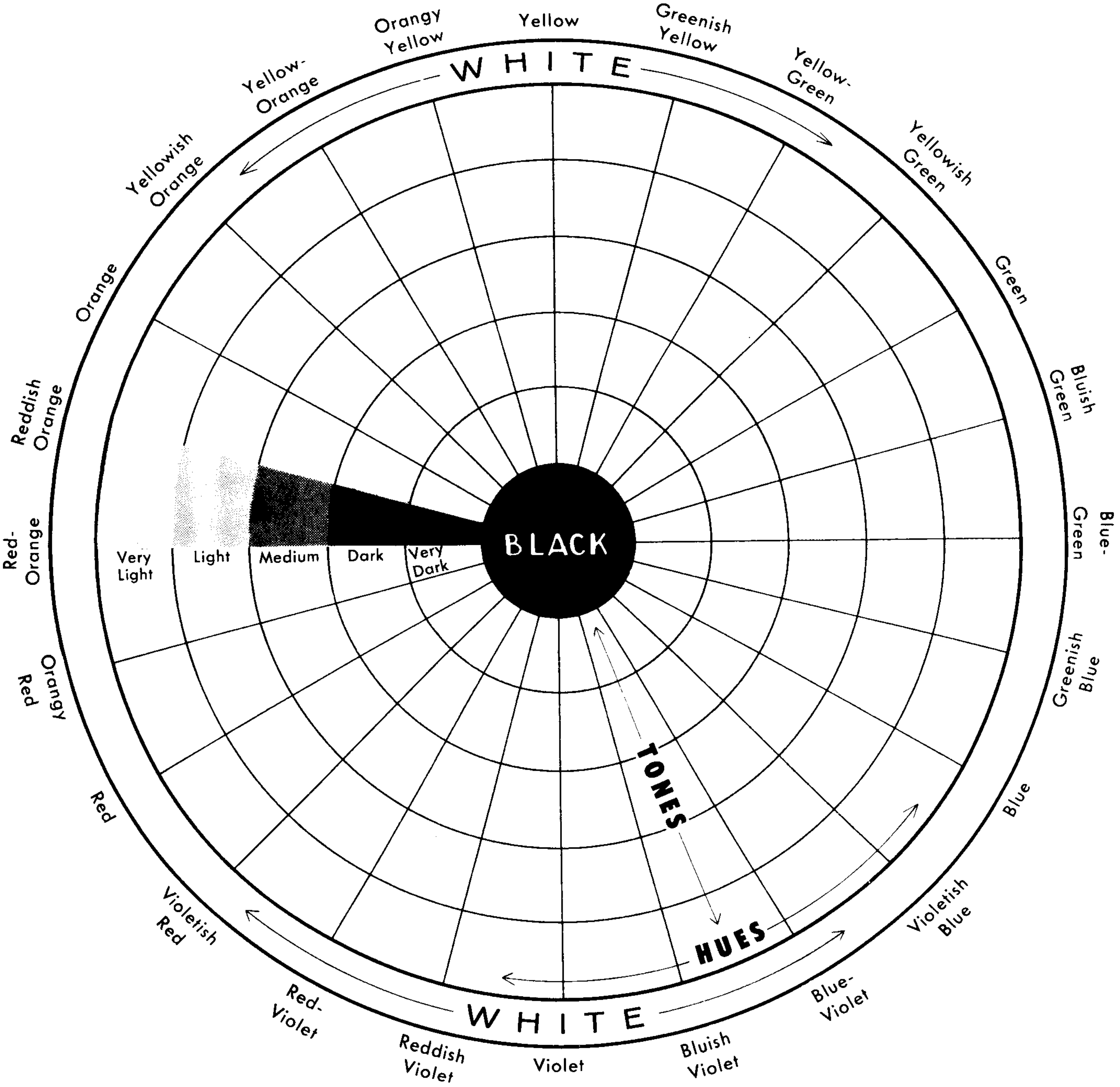
Intensity is that attribute by which a color is distinguished as being vivid or dull and by which the eye perceives it as holding a position on a scale of vividness to dullness or grayness. The intensity of any hue can be lowered from a maximum by the admixture of gray. The intensity of a gem's color is described by the use of the terms HIGH (or VIVID), MEDIUM or LOW, and additionally by the adjectives GRAYISH or BROWNISH for still lower intensities (the term brown applies to low intensities of red-orange and yellow).

C. Complementary Hues.

Reference to the accompanying color wheel will show that each hue has another hue exactly opposite it. Pairs of opposite colors are referred to as COMPLEMENTARY COLORS. On the wheel, red, yellow and blue are the PRIMARY COLORS and their complements are referred to as SECONDARY COLORS. Pigments of any of these opposite colors that are used commercially in paints and in art work will, when mixed in equal quantities, produce gray.

It is interesting to note that if any intense hue is viewed for a short time in neutral surroundings and the eye is then shifted to a pure white surface, the surface will apear as the complementary color of the hue. This is

# DIAGRAMMATIC CHART OF COLOR DESCRIPTION



easily explained by the fact that the sensation produced in the eye by visible light involves a chemical reaction: the subsequent temporary depletion of chemicals in the activated receptors of the eye results in these receptors being incapable of a full response when exposed to the white background. Thus the normal stimulation of the remaining receptors becomes, in effect, the equivalent of an exposure to the opposite, or complement, of the color just observed. Such an effect is called an AFTERIMAGE.

### D. Pigments and Absorption.

The color of an object when illuminated by white light is, as stated previously, the result of the object's ability to selectively absorb, or subtract, certain of the wavelengths of the light reflected from, or transmitted through, it. The resulting colors are called SUBTRACTIVE COLORS. The color circle is therefore a SUBTRACTIVE COLOR WHEEL. It does not convey the reactions and resultant colors that would be obtained if colored lights were directed at, and thus superimposed on, a white background that, in turn, would reflect all wavelengths directed at it. For example, mixing pigments of the three primary hues on the subtractive color wheel will result in black, since between the three all of the wavelengths of light directed at the mixture will be absorbed. Three light sources, however, each producing wavelengths that are representative of the three primary hues, if superimposed, will produce white, since, by addition, all of the wavelengths necessary to stimulate the three types of receptors in the eye are added together. A color wheel used to illustrate the effects of adding light from colored illuminants is referrd to as an ADDITIVE COLOR WHEEL. It is not illustrated here, because it has no application in the classification and description of colored stones.

## II. THE STRUCTURE OF MATTER.

The competent gemologist has less need for a detailed knowledge of the chemical properties of gemstones than he does for optical and other physical properties. Nevertheless, there are times when a fundamental knowledge of the structure of matter and of basic chemistry is of great value. Minerals are classified by the mineralogist on the basis of chemical composition. The manner in which the atoms that compose them are joined together is a major factor in determining physical properties, and the nature of the atoms has a major bearing on chemical properties. In the next few pages a brief, fundamental background for chemistry is given. This is included to provide basic information for those who would like a better understanding of the fine structure or gem materials, the causes of color in transparent gemstones, and the nature of inclusions. Because of the nature of the subject and the fact that an understanding of it is not required for a mastery of grading and identification, no questions will be asked about the structure of matter on examinations.

Year by year, during the last half century, the study of the fine structure of matter has intensified and the value of that knowledge has become increasingly obvious. Many years ago it was shown that elements were related in certain definite ways. It became clear that each step upward in atomic weight was a step upward in complexity of structure. Niels Bohr, the Danish physicist, demonstrated that atoms could be visualized readily as minute solar systems, with massive, positively charged particles (PROTONS) in the center and with less massive, negatively charged particles (ELECTRONS) moving rapidly in orbits about it. Each step upward from element #1 to element # 92 means an increase of one proton in the nucleus of an atom and one more electron moving rapidly about it. The nucleus of each atom is composed of the densest substance known to man. It consists of positively charged protons and uncharged particles called NEUTRONS. The density of neutrons and protons is so great that, if it were possible to pack the nuclei of atoms together until they reached the size of a child's marble, the weight of the sphere would be approximately 250 million tons! The negatively charged electrons have a density of roughly 1/1800th of a proton, although their size is comparable.

The miniature solar systems increase in complexity in steps as more protons, more neutrons and more electrons are added with increasing atomic number. Thus hydrogen, which has one proton and one electron, finds one electron moving in all directions about its single proton nucleus. In helium, the element with the atomic number of two, there are two electrons that move about it the same distance from the center. The next eight elements have atoms in which the additional electrons move in a second energy level outside of the first level, in which only two are located. The next step upward is another energy-level figure that has from one to eight electrons, depending on the atomic number of the element, and this is followed by a level in which eighteen may be found and another with a maximum potential of thirty-two. The last energy level is known to be an incomplete one in which, of the natural elements found on earth, uranium, #92, is the most complex. It has six electrons in its outer shell, with a maximum number in each of the inner shells. The artificial radioactive elements made in the particle accelerators of nuclear physicists are made by adding protons to the center and additional electrons to the outer ring.

The manner in which an element behaves chemically is determined in a large measure by the relationship of the number of electrons in its outer ring of electrons and the number that would be necessary to complete that energy level. Since the innermost energy level contains two electrons, helium, which has only two, has a complete first energy level. It is inert chemically. There is no tendency for it to combine with other elements; thus it is called a NOBLE GAS. In steps of increasing complexity, up through the periodic table of elements in each situation where the outer ring has a full complement of electrons, the element is a noble gas. In general, those elements that lack one, two or three electrons of having full outer rings are the nonmetallic elements, including the halogens (fluorine, chlorine, bromine, etc.), oxygen, sulphur, selenium, tellurium, nitrogen and phosphorus. Generally, those that have only one, two or three electrons in the outer ring are metals.

Compounds are formed in various ways. The most important is that in which electrons are transferred from a metallic element with one, two or three it can "spare" to a nonmetallic element that is lacking electrons in its outer energy level. Table salt, for example, is formed by the combination of sodium and chlorine; sodium has only one electron in its outer ring and chlorine lacks one. If effect, sodium lends an electron to chlorine and the combination forms a new material with properties unlike those of either of its constituents. If a material such as chlorine (Cl), which lacks one electron in its outer ring, combines with a material such as carbon (C), which has four, it requires four chlorine atoms to provide four spaces for the extra electrons of carbon. Under these circumstances, chlorine is said to have a VALENCE of minus one and carbon is said to have a valence of plus four (+4), meaning that it has four to contribute from its outer ring. Thus a compound of these two elements is abbreviated as $CCl_4$.

Under certain circumstances, elements behave differently. For example, chlorine could give up seven electrons instead of taking one. Iron (Fe) may have a valence of +2 or +3; therefore, it may form compounds with oxygen (valence minus 2), either as FeO or $Fe_2O_3$. Since oxygen has a -2 valence, FeO is $Fe^{+2}O^{-2}$ and $Fe_2O_3$must be $Fe_2^{+3}O_3^{-2}$. $Fe_2O_3$ is the formula for hematite. Ordinarily, a compound must have a balance such that positive and negative valences add up to zero; thus spinel is $MgAl_2O_4$. Magnesium (Mg) has a valence of +2 and oxygen (O) is usually -2, so aluminum (Al) must be +3, because $MgAl_2O_4$ would be +2, ?, -8. 2Al must be +6, so Al = +3. In each compound in which there are metallic and nonmetallic elements, positive and negative valences are balanced. Some compounds containing only nonmetallic elements do not pass an electric current; therefore, the idea of positive and negative valences does not apply. These are called COVALENT, since they share electrons rather than transfer them one to another.

Because the most abundant and gemologically most important elements have low atomic numbers, they have relatively simple atomic nuclei. It is interesting, too, that elements of even atomic number are much more abundant than the odd numbers.

## III. EFFECTS OF ACIDS.

The vulnerability of the various gemstones to acids differs widely. Some must be treated with the utmost care, but others are totally insoluble, for all practical purposes, even in hot concentrated acids.

Undoubtedly, the most susceptible of all gem materials is the pearl. Pearls are composed primarily of calcium carbonate in the form of the mineral aragonite. The carbonates are very soluble even in weak, diluted acids. Thus pearl, coral, shell and malachite must be protected against acids of any kind. These materials, plus turquois, are among the few that are not exceedingly insoluble. The reason that most gem minerals exist for such great lengths of time in the earth's crust before being discovered is their resistance to being taken into solution by circulating ground waters, many of which are either weakly acidic or weakly basic. Thus they are resistant to both chemical changes and physical forces.

There are other colored stones on which the use of certain acids may be dangerous. Peridot is attacked by hydrochloric acid, but too slowly at normal temperatures to be a serious problem in repair work; the same is true of hematite. Turquois dissolves in the same acid at a rate that demands that the porous gem mineral be kept away from acids. Lapis-lazuli must also be protected from hydrochloric acid, for it decomposes slowly.

Glass, quartz, chalcedony and opal are attacked in varying degrees by the glass-etching acid, hydroflouric. It dissolves quartz more slowly than glass or opal, but at a significant rate.

Some plastics are attacked by acids, whereas others are highly resistant. Other solvents, such as acetone and carbon tetrachloride, dissolve or soften some plastics.

## IV. CAUSES OF COLOR.

Earlier in this assignment, it was made clear that the cause of color in transparent gemstones is selective absorption, but little was said about the CAUSE of differential absorption and transmission of the various wavelengths. It is obvious that gemstones such as corundum and tourmaline, both of which occur in colorless forms as well as in numerous colors, must owe their color absorption to something that is not found in every stone of the species. Gem species of this kind have been shown by very careful chemical analyses to be colorless when absolutely pure. The various colors in which they occur vary according to the percentages of metallic oxides that are present in minute quantities as impurities. Such gem minerals are called ALLOCHROMATIC (pronounced al-oh-kro-MAT-ik). Those in which as essential chemical element is responsible for the color are said to be IDIOCHROMATIC (pronounced id-ee-oh-kro-MAT-ik). Examples of the latter are turquois, peridot and malachite. Therefore, all specimens of an idiochromatic species are quite similar in color.

Prior to the introduction of the synthetic gem materials, causes of color were theorized on the basis of very accurate chemical analyses and by the results of the addition of various quantities of different substances to glass melts. Careful analyses of blue sapphire showed traces of iron and titanium, whereas ruby showed small amounts of chromic oxide. (Note: It is interesting that the chromium atoms replace aluminum in the corundum structure readily, which accounts for the fact that rubies are usually fairly evenly colored. On the other hand, the iron and titanium oxide that colors sapphire is present in a combined state in the form of the mineral ilmenite ($FeTiO_3$), which is in a colloidal form. This may be the reason that sapphires are usually somewhat unevenly colored and that synthetic sapphires of a fine blue color have not been made.) Since these were the only differences detected, the conclusion was inescapable. The Verneuil process for the synthesis of corundum confirmed suspicions along these lines, for it was found that oxides of various metals produced the desired and expected results. Subsequently, many different metallic oxides were tried, with the result that some colors were produced that are not known in nature.

As you have learned, synthetic gem materials duplicate their natural counterparts in both composition and structure; as a result, their properties are substantially identical. When speaking of corundum and synthetic corundum, the term "identical" applies without qualification with respect to structure, properties and composition. Synthetic spinel is not exactly the same in composition; consequently, its properties differ somewhat, but the structure of the natural and synthetic are the same. Synthetic spinel was first made accidentally when magnesium was added to aluminum oxide in a effort make blue synthetic sapphire. Fine blue in the synthetic sapphire had proved impossible to make, so many experiments were tried to improve the situation, without success. Even today, dark-blue synthetic spinel is much closer in appearance to top-quality blue saphire than is any synthetic sapphire.

Synthetic emerald (beryl) has been made successfully in commercial sizes for many years. It was first made in Germany in 1935. Those now on the market are manufactured in San Francisco by Carroll Chatham, a chemist. Quartz, which also possesses a simple chemical composition, is made synthetically, but it is inexpensive enough in its more usual varieties to make its manufacture commercially unprofitable for gem purposes. Diamonds are made synthetically in minute sizes (several thousand pieces per carat) for industrial purposes by the General Electric Company.

Identical reproduction of the chemical composition of a genuine stone does not constitute a synthetic reproduction of the genuine, unless the reproduction also has the same arrangement of atoms in its crystal structure and the same physical and optical properties. Manufactured "copies" of gems that have the same chemical composition and color as the genuine, but that do not reproduce their crystal structure, are glass and are classified as imitations. For instance, a certain emerald-green material made of $BeAl_2(SiO_3)_6$, which is the formula for geniune beryl, is not a synthetic emerald but an imitation, since it does not also have the same atomic structure as the geniune. Lacking the same structure as geniune emerald, it has different physical and optical properties. Since it has an amorphous structure, it is merely a glass imitation, even though it does possess the same chemical composition as emerald.

The color of synthetic corundum and synthetic spinel is produced by the addition of a small amount of a metallic oxide (a combination of a metallic element and oxygen) to the powdered compound of the species before it is fused. Different oxides are used to produce various colors. The green color of synthetic emerald is produced by the addition of chromic oxide.

Glass is actually more a physical state than a chemically definable material. It may be thought of as a supercooled liquid, so viscous that, for all practical purposes, it is rigid. It may be made with a wide variety of constituents, although the key ingredients are metallic oxides. Almost always a major constituent is silica (silicon oxide) in the form of pure sand. Oxides of sodium and calcium are usual constituents as well. Lead, boron or potassium oxides are also used frequently, but the composition depends on the properties desired. Most fine tableware and many gem imitations have a large lead-oxide content. Small amounts of other metallic oxides act as colorants; e.g., cobalt for blue.

## V. CHANGE AND LOSS OF COLOR.

### A. Heat Treatment.

The color of some gemstones changes when they are subjected to heat. Gems thus treated are sometimes called "fired" or "burnt" stones. Such changes may be temporary, resulting in immediate reversion to the original color as the temperature returns to normal. Thus, ruby, which changes to green at high temperatures, reverts to its original color upon cooling. In other cases, reversion to the original color, or to one somewhat similar, may be gradual or may not be detectable even after many years. For instance, some zircons that have been heat treated to produce a blue color revert partially over a period of time; others seem to be permanently colored. In some heat-induced color changes, the result may be permanent every time; the brownish topaz-quartz that is produced by heating some amethyst-colored quartz is an example.

B. Dyed Stones.

A few gemstones are permanently changed in color by chemical treatment; heat is also usually applied during the treatment. This change of color is sometimes permanent, as in the case of chalcedony stained black. More often the color changes gradually, as it does in blue-dyed quartz. On the other hand, many stones are stained with dyes that change color quickly.

C. Loss of Color.

Exposure to heat or light may result in gradual and complete loss of color. Examples are the production by heat treatment of colorless zircons from colored specimens of that gem mineral, and the gradual loss of color in rose quartz when exposed to daylight over a long period of time. The majority of dyed stones lose color under either heat or light.

## VI. COLOR IN METALS.

Under ordinary conditions of illumination, the precious metals have a distinctive color. This color is often greatly modified by light reflections from the metals' surfaces. Pure gold under bright lights appears a different color than under very diffused light. Usually, the distinctive color of a metal is apparent in the color of any alloy of which it is an important constituent, such as the color of coper in 10-karat gold. However, mixtures of metals may result in an alloy that retains little of the distinctive color of the metal that is its principal constituent. This is true of 18-karat white gold used in jewelry.

## VII. THE NATURE OF INCLUSIONS.

During the growth of any kind of gem material in nature or in the laboratory, foreign materials or small crystals of the same material are often caught up in the accumulating matter, or structural irregularities appear. If the gem material is transparent, and if the enclosure is large enough, it may be visible to the unaided eye or under sufficient magnification. Materials caught up during the growing process are called INCLUSIONS. Fissures, cleavages, fractures and nicks are more accurately described as IMPERFECTIONS, FLAWS or BLEMISHES.

Rather than regarding inclusions in colored stones as harmful, in small sizes and numbers that do not detract in any way from their beauty they should be regarded as adding to desirability, for they provide identifying characteristics. Not only do they separate that stone from any other stone of the same variety, but in the natural they prevent confusion at a later date with what synthetic materials may then be available. Dealers tend to regard colored stones as perfect when they contain no flaws that are visible to the unaided eye. In the more expensive qualities of the more valuable gemstones, flawlessness under 10x is all but unknown. In addition, since ruby, sapphire and emerald are synthesized in large quantities, it is better for the fine natural stones to contain identifying characteristics.

Inclusions may be solid, liquid or gas or combinations thereof. Solid inclusions may be of the same material but oriented or coated in such a manner that they remain visible, or they may be of any foreign matter that was present during their growth. Liquid inclusions usually, but not always, contain gas bubbles. The liquid is generally of the same composition as that of the solution in which the crystal grew. Some natural gemstones and almost all stones synthesized by the Verneuil process (corundum, rutile, spinel and strontium titanate) may contain gas bubbles that were caught up in the molten material as it solidified. Glass, both natural and artificial, as well as amber, may also contain spherical or elongated gas bubbles. Natural crystalline gemstones do not contain spherical gas bubbles, except in angular cavities containing both liquid and gas; however; some stones, such as diamonds, have white, cloudy inclusions that may be gas-filled enclosures.

Another characteristic usually considered under inclusions is color banding. In addition, twinning planes, which show up as discontinuities in a stone, are considered under inclusions. The same is true of growth lines such as the striae seen in synthetic corundum and the swirl marks in glass.

A knowledge of the difference between the appearance of inclusions resulting from artificial manufacture and the inclusions of other minerals or liquids that occur in geniune stones is necessary to become an expert in the detection of synthetic gem materials.

Inclusions and growth structures will be given more detailed consideration under the various gemstones later in this course.

## ELEMENTS IN THE IMPORTANT GEMSTONES AND THEIR SUBSTITUTES

| Atomic Number | Name | Symbol | Atomic Weight | Common Valences in Gem Minerals |
|---|---|---|---|---|
| 1 | Hydrogen | H | 1.0078 | +1 |
| 3 | Lithium | Li | 6.940 | +1 |
| 4 | Beryllium | Be | 9.02 | +2 |
| 5 | Boron | B | 10.82 | +3 |
| 6 | Carbon | C | 12.00 | +4, -4 |
| 7 | Nitrogen | N | 14.008 | +5, -3 |
| 8 | Oxygen | O | 16.00 | -2 |
| 9 | Fluorine | F | 19.00 | -1 |
| 11 | Sodium | Na | 22.99 | +1 |
| 12 | Magnesium | Mg | 24.32 | +2 |
| 13 | Aluminum | Al | 26.97 | +3 |
| 14 | Silicon | Si | 28.06 | +4 |
| 15 | Phosphorous | P | 31.02 | +3, +5 |
| 16 | Sulphur | S | 32.06 | -2, +6 |
| 17 | Chlorine | Cl | 35.457 | -1 |
| 19 | Potassium | K | 39.096 | +1 |
| 20 | Calcium | Ca | 40.08 | +2 |
| 22 | Titanium | Ti | 47.90 | +4 |
| 24 | Chromium | Cr | 52.0 | +3 |
| 25 | Manganese | Mn | 54.9 | +2 |
| 26 | Iron | Fe | 55.8 | +2, +3 |
| 29 | Copper | Cu | 63.57 | +1, +2 |
| 30 | Zinc | Zn | 65.4 | +2 |
| 38 | Strontium | Sr | 87.63 | +2 |
| 40 | Zirconium | Zr | 91.22 | +4 |
| 56 | Barium | Ba | 137.36 | +2 |

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# CHEMICAL COMPOSITION OF GEMSTONES

## ELEMENTS

| | |
|---|---|
| Diamond | $C$ |

## SULPHIDES

| | |
|---|---|
| Marcasite | $FeS_2$ |
| Pyrite | $FeS_2$ |

## OXIDES & HYDROXIDES

| | |
|---|---|
| Corundum | $Al_2O_3$ |
| Hematite | $Fe_2O_3$ |
| Opal | $SiO_2.nH_2O$ |
| Quartz | $SiO_2$ |
| Synthetic corundum | $Al_2O_3$ |
| Synthetic rutile | $TiO_2$ |
| Strontium titanate | $SrTiO_3$ |

## HALOIDS

| | |
|---|---|
| Fluorite | $CaF_2$ |

## CARBONATES

| | |
|---|---|
| Azurite | $2CuCO_3Cu(OH)_2$ |
| Calcite | $CaCO_3$ |
| Malachite | $CuCO_3Cu(OH)_2$ |
| Smithsonite | $ZnCO_3$ |

## ALUMINATES

| | |
|---|---|
| Chrysoberyl | $BeAl_2O_4$ |
| Spinel | $MgAl_2O_4$ |

## PHOSPHATES

| | |
|---|---|
| Apatite | $Ca_5(F,Cl)(PO_4)_3$ |
| Lazulite | $(Fe, Mg)Al_2(OH)_2(PO_4)_2$ |
| Turquois | $H_5(Al(OH)_2)_6CuOH(PO_4)_4$ |
| Variscite | $AlPO_4.2H_2O$ |

## SILICATES

| | |
|---|---|
| Almandite | $Fe_3Al_2(SiO_4)_3$ |
| Andalusite | $Al_2SiO_5$ |
| Andradite | $Ca_3Fe_2(SiO_4)_3$ |
| Axinite | $HCa_3Al_2B(SiO_4)_4$ |

## SILICATES, CONT'D.

| | |
|---|---|
| Benitoite | $BaTiSi_3O_9$ |
| Beryl | $Be_3Al_2(SiO_3)_6$ |
| Chrysocolla | $CuSiO_3.nH_2O$ |
| Diopside | $CaMg(SiO_3)_2$ |
| Dioptase | $H_2CuSiO_4$ |
| Enstatite | $MgSiO_3$ |
| Epidote | $Ca_2Al_2(AlOH)(SiO_4)_3$ |
| Euclase | $Be(AlOH)SiO_4$ |
| Fibrolite | $Al_2SiO_5$ |
| Grossularite | $Ca_3Al_2(SiO_4)_3$ |
| Idocrase | $Ca_6Al(OH,F)Al_2(SiO_4)_5$ |
| Iolite | $(Mg,Fe)_4Al_8(OH)_2(Si_2O_7)_5$ |
| Jadeite | $NaAl(SiO_3)_2$ |
| Kyanite | $Al_2SiO_5$ |
| Microcline | $KAlSi_3O_8$ |
| Nephrite | $CaMg_5(OH)_2(Si_4O_{11})_2$ |
| Orthoclase | $KAlSi_3O_8$ |
| Peridot | $(Mg,Fe)_2SiO_4$ |
| Phenakite | $Be_2SiO_4$ |
| Prehnite | $H_2Ca_2Al_2(SiO_4)_3$ |
| Pyrope | $Mg_3Al_2(SiO_4)_3$ |
| Rhodonite | $Mn_2(SiO_3)_2$ |
| Serpentine | $H_4Mg_3Si_2O_9$ |
| Sodalite | $Na_4Al_2(Al,Cl)(SiO_4)_3$ |
| Spessartite | $Mn_3Al_2(SiO_4)_3$ |
| Sphene | $CaTiSiO_5$ |
| Spodumene | $LiAl(SiO_3)_2$ |
| Synthetic emerald | $Be_3Al_2(SiO_3)_6$ |
| Topaz | $Al_2(F,OH)_2SiO_4$ |
| Tourmaline | a very complex silicate of boron, aluminum and several other metals. |
| Wilemite | $Zn_2SiO_4$ |
| Zircon | $ZrSiO_4$ |

(CS, #11, p. 12)